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# The AFRL Line-Imaging ORVIS


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AFRL/RWMW has built a new diagnostic tool for shock-wave studies. The diagnostic tool is called ORVIS, and is capable of tracking very high velocities with high temporal resolution. The tool also is spatially resolved in one dimension, so that the velocities along a line of material are tracked. This report describes the physical layout of the system, a description of the operational theory and principles, guidelines for setup and usage, and specifics about key components of the system.

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# The AFRL Line-Imaging ORVIS

General Description and Operating Guidelines

Prepared by: Wayne M. Trott, Interferometry Consultant
for
AFRL Personnel working with the Line ORVIS at Eglin AFB
and
Edited by:  Christopher Neel, AFRL/RWMW

September 2013

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## 1. Work Summary

The AFRL Line-Imaging Optically Recording Velocity Interferometer System (ORVIS) is a custom designed and assembled velocity interferometer for measurement of spatially resolved wave profiles (along a line segment) generated in impact studies at the AWEF gun facility at Eglin AFB. This work was performed in fulfillment of Reynolds Systems Inc. Purchase Order No. 5-8918 (Eglin AFB Contract F1TBAX2194BG03, FA8651-11-D-0109, TO0007 line VISAR with RSI). The work was performed in several phases. In January 2013, Interferometry Consultant (IC) met with AFRL personnel on-site at Eglin AFB to discuss experimental needs and to define the basic layout of the Line-ORVIS system. At this time, it was decided to utilize an optical table already available at the facility and to design the instrumentation to fit the 72” x 59” area of this platform. Over the next several months, IC (with ongoing consultation with AFRL personnel by e-mail) developed a detailed design for the interferometer and its coupling to the gun target chamber at the AWEF facility. The required discrete optical and optical mounting components were identified and ordered from commercial suppliers. An acousto-optic modulator system and motorized actuators were also ordered for this system. (A detailed list of the ordered material is available upon request.) The system utilizes a streak camera/intensifier/CCD camera system that had been previously acquired by AFRL. A more detailed description of the various elements in the interferometer design is given below. After delivery of nearly all of the components to Eglin, IC made a second on-site visit in May 2013 to assemble (with the aid of AFRL personnel) the interferometer and the coupling set up to the gun target chamber. Initial training in the use of the accompanying data reduction software (available from Sandia National Laboratories) also took place at this time. A third visit was made in July 2013 to complete the set up, provide training on its operation, assist in coupling the interferometer signal to the streak camera detector, and oversee the implementation of this diagnostic on a gun test. A successful test of the interferometer was performed on July 11, 2013. The work performed off-site and on-site fulfills the tasks outlined in the statement of work submitted for this contract.

## 2. System Description

The AFRL system is essentially a very-long-working-distance projection microscope coupled to an ORVIS-style interferometer. The important elements of the optical design are shown schematically in Figure 1. This illustration portrays the approximate geometry of the layout but it is not drawn strictly to scale.

Coherent, continuous-wave (cw) light from the user-supplied Verdi Nd:$YVO_4$ laser is coupled to an acousto-optic modulator that is driven by a RF modulator driver, generating a first-order beam that is deflected at a small angle to the transmitted zero-order beam. The first-order beam can be gated on and off as desired through

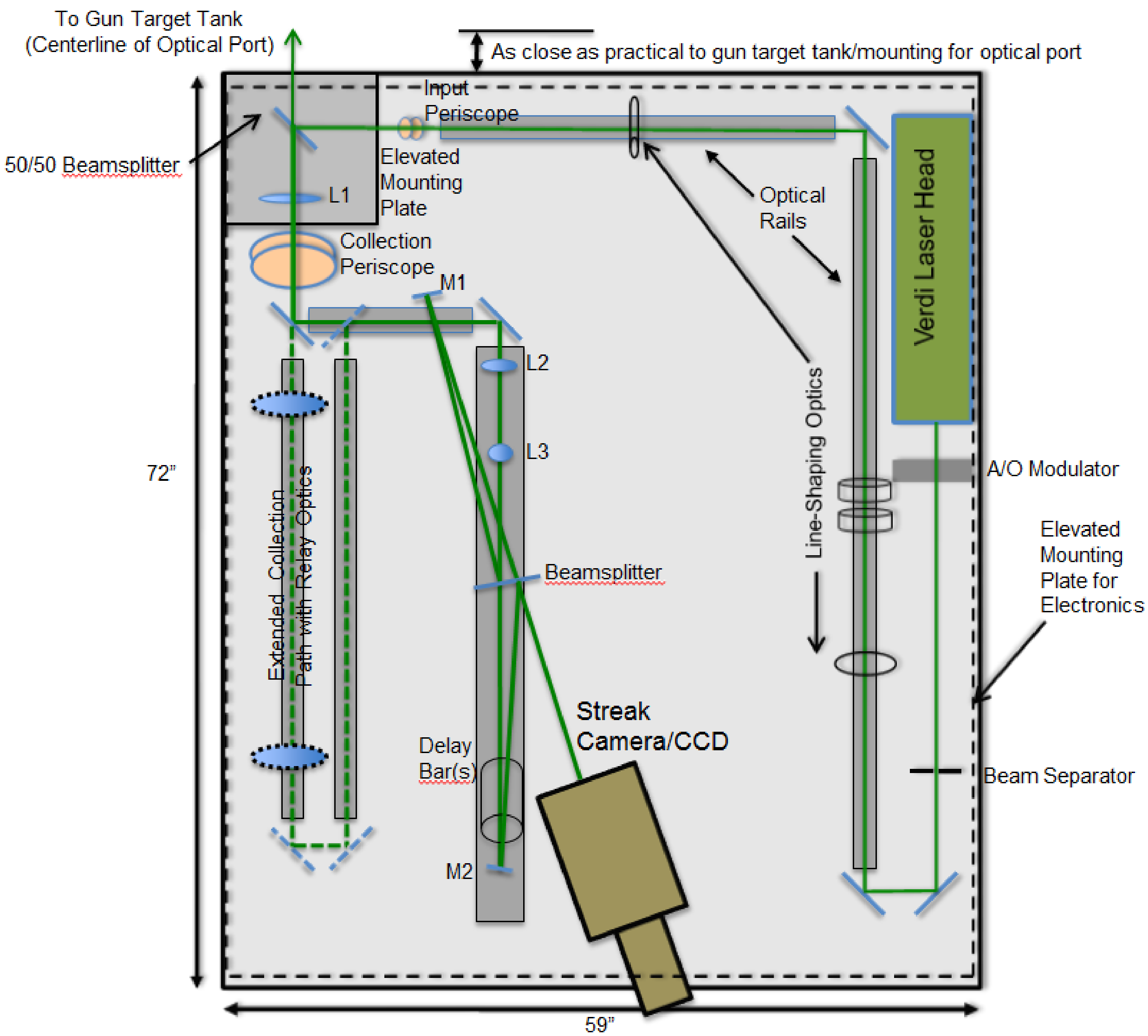


Figure 1. Schematic diagram of AFRL Line-Imaging ORVIS

application of voltage pulses to the system from a user-supplied signal/delay generator. In this manner, either a single light pulse (~1 ms duration or less) or multiple pulses at a frequency dictated by the user can be supplied to the interferometer system. The single-pulse mode can be externally triggered by the gun system target pins and is useful for minimizing the amount of light resident on both the target and the diagnostic instrumentation while the gun is being charged and fired. The multiple pulse mode provides a flexible and convenient method for adjusting the light intensity needed for set up and alignment while allowing the laser to operate at the appropriate power levels for best performance.

A small aperture (beam separator) is used to separate the first-order beam from the zero-order and any higher-order beams. Three turning mirrors are used to direct this beam along a defined path to the input periscope at an approximate elevation of 8” above the optical table surface. These mirrors are high reflectors that are coated for the vertical laser polarization and are suitable for high-power operation. Iris diaphragms (not shown in Figure 1) mounted on two optical rails are used to align to the desired laser path. Alignment is initially achieved along the first optical rail and the beam is then directed by the third turning mirror along the path above the second rail that is mounted at a $90^o$ angle to the first. A useful method for alignment along the first rail is to adjust the first two turning mirrors iteratively to direct the beam through two irises. This is typically done using visual inspection to roughly center the beam on the iris apertures and then the process is refined by placing a slightly roughened piece of mylar (or similar material) ahead of the diaphragm and viewing the combination specular/diffuse spot behind the diaphragm. This technique yields a more precise alignment of iris aperture and light beam than can be achieved through simple visual inspection alone.

Once alignment is achieved along the first optical rail, the third turning mirror can be used to direct the beam along the desired path above the second rail through iterative adjustments of x/y translation relative to the optical table and the tip/tilt drives in the optical mount. Once proper beam alignment along the two rails is achieved, the various lens elements comprising the line-shaping optics can be carefully aligned to this beam path, as shown schematically in Figure 1. Chronologically, the placement of the line-shaping optics is one of the last steps in setting up for a shot and this process is described in more detail later. Note that the design of the very long initial path defined by the two optical rails (and associated optics) was driven in large part by the very long distance involved in coupling to the gun target. In particular, this situation requires a large separation between the first and last elements of the line-shaping optics assembly.

The assembly for raising the beam to the ~56” height of the gun barrel/target centerline is located at one corner of the optical table and the table itself is located as close as reasonably practical to the optical port on the gun target chamber. The intent of this design was to minimize the area in which the beam (as well as associated reflections from the target) propagates near eye level. Two additional high reflectors are used in the input periscope. In aligning these optics, considerable care needs to be taken to ensure that the turning angles are as close to $90^o$ as possible. The beam is then routed into the target chamber by reflection off of a 4”-diameter 50/50 beamsplitter. Once again, it is important to achieve a turning angle very near $90^o$. Proper handling of stray beams in this area is very important. This includes the portion of the beam *transmitted* by the beamsplitter as well as the back reflection from the nearby optical port on the gun target chamber.

Once inside the target chamber, the beam is directed by a user-supplied, “throwaway” first-surface mirror to the desired position on the gun target. Light reflected from the target is routed back out of the target chamber using the same first-surface mirror. To the extent possible, maintenance of $90^o$ turning angles and beam propagation parallel to the floor is desirable. The reflected light passes through the 50/50 beamsplitter and is collected and roughly collimated by the lens labeled L1 in Figure 1. For various reasons (including application of simple lens formulas to the optical design), it is helpful to have the focal length of this lens roughly match the distance to the target. IC was able to obtain a 128-mm-diameter, 1920-mm focal length lens that is fairly well matched to the ~2.2-meter distance to the target. In its current mounting in a 4”-diameter tip/tilt mount, the *f/#* of the collection optics is fairly high which places a premium on target design that optimizes the geometry of the reflected light. This issue is discussed in more detail below.

The collected light from the target is brought down to the desired 8” height above the optical table by the collection periscope. This assembly includes two 3”-diameter high reflectors. It is again important to achieve turning angles near $90^{o}$. Poorly controlled alignment at this stage can result in a target image at the streak camera that is significantly “tilted.” The reflected light is then either routed by a 3”-diameter turning mirror to the interferometer assembly or along an extended path that can incorporate additional relay lenses. The latter setup provides additional flexibility in adjusting the image magnification at the streak camera. As the light approaches the interferometer, it is important to ensure that stray reflections (e.g., from back reflection at the optical port or a target interferometer window) are effectively blocked so that only light from the interface of interest is passed into the system (to the extent possible).

The reflected light is then aligned along the interferometer axis using either the turning mirror downstream of the collection periscope or a turning mirror placed at the end of the extended collection path in combination with the turning mirror at the front end of the optical rail containing the interferometer optics. The alignment procedure is similar to that used in the input leg; the two turning mirrors are adjusted iteratively to align the beam to iris diaphragms mounted along the optical rail. Before the interferometer beamsplitter (see below) is installed or repositioned, one iris can be adjusted to the correct height and the optical path down the rail can be established by moving the iris forward and backward on the rail and iteratively adjusting the two turning mirrors. After the beamsplitter is in place, the second iris can be positioned downstream of the beamsplitter and aligned to the established optical path. In this manner, the small horizontal offset arising from refraction in the beamsplitter can be accounted for. The light spot is reduced in diameter by the down-collimating telescope optics (L2, L3). A 50/50 beamsplitter splits the beam into two equal-intensity components, one of which serves as a reference leg. A 4”-diameter optic coated for 50/50 reflection at an incident angle of $10^{o}$ is used for this purpose. Typically, the reflectance coating is positioned to be on the front (or input) side of the beamsplitter. The reference leg reflects off mirror M1 and is passed through the beamsplitter on its way to the recombination plane at the slit of streak camera. The second leg (initially transmitted by the beamsplitter) passes through a variable-length fused silica cylinder. This optical component imparts a time delay (proportional to the cylinder length) in the second beam. Mirror M2 then reflects this beam back through the cylinder to the front surface of the beamsplitter at an angle such that it overlaps the reference leg at the recombination plane. Mirrors M1 and M2 are high reflectors coated for maximum reflection at an incident angle near $0^{o}$. Mirror M2 is then tilted at an additional small angle in order to produce a straight-line interference pattern at the recombination plane. To maintain good beam overlap at the recombination plane, it is also necessary to translate M2 a small distance along the interferometer axis. (Many additional helpful details pertaining to the basic ORVIS interferometer design and characteristics can be found in the original reports by Bloomquist and Sheffield.[*]) The rotation and translation of M2 to produce the optimal fringe pattern are precision adjustments that are aided by a motorized translator and a motorized mirror mount that enables extremely fine tip/tilt motions. A spreadsheet that correlates the necessary translation distance to the desired fringe density at the streak camera slit is supplied along with the data reduction software. Further information regarding the interferometer settings is given below.

Typically, the interferometer recombination plane is set to correspond to the position of the slit of the recording streak camera. However, it is also possible and sometimes convenient to establish an intermediate recombination plane and use relay optics to re-image the recombination plane to the streak camera slit. The streak camera is aligned so that the center of the slit lies perpendicular to the optical axis of the interferometer. The key adjustments here are the streak camera height (the slit should be positioned at the established height of the optical path), horizontal translation (so that the optical path falls on the center of the slit), and the tilt of the streak camera body. Correct tilt can be established by placing a first-surface mirror on the front surface of the camera and then adjusting the camera position so that the light from the interferometer is reflected back upon itself. Adjustment of the tilt, translation and height of the camera can be done iteratively until the correct alignment is achieved while also monitoring the camera level at the top surface.

[*]D. D. Bloomquist and S. A. Sheffield, J. Appl. Phys. **54**, 1717 (1983); D. D. Bloomquist and S. A. Sheffield, "ORVIS, Optically Recording Velocity Interferometer System, Theory of Operation and Data Reduction Techniques," Sandia Report, SAND82-2918, February 1983.

## 3. Safety Considerations

**Since the AFRL Line-Imaging ORVIS is an imaging interferometer, it incorporates by design and necessity an open-beam laser system. As such, it must be considered a hazard to both eyes and skin if the laser energy is improperly controlled and must be operated with the extreme care appropriate to open-beam laser operation.**

To mitigate the hazards associated with the operation, IC highly recommends the following:

- Reference to and operation consistent with ANSI Z136.1 (2007)—American National Standard for Safe Use of Lasers.
- A thorough review of the optical setup by the facility/site laser safety program.
- Continued use of the laser enclosure panels available for this operation.
- Continued utilization of engineering controls as the primary means to achieve control on the laser energy to the extent possible.

- Availability and use of laser eyewear appropriate to Maximum Permissible Exposure values and the specific tasks at hand.
- A thorough examination of the system for stray laser reflections and placement of suitable beam blocks to prevent eye exposure to these reflections. Note: This should be repeated after any significant change in the optical configuration.
- Operation of the laser/AO modulator at the least possible power setting to complete the alignment and setup.

IC also recommends the following:

- Provide physical enclosures for the open beam where it is practical.
- Use remote viewing of the beam where it is practical—this should be especially considered at the target surface and at the slit of the streak camera.
- When using a mylar diffuser for alignment, the piece should be firmly mounted so that the mylar surface remains perpendicular to the optical table surface. This is to prevent strong reflections from the mylar surface leaving the plane of the optical alignment.

# 4. General Guidelines for Interferometer Operation

## 4.1. Alignment

Best performance is achieved by establishing and adhering to a defined optical path to and from the experimental target. Remove all lenses (line-shaping optics, relay lenses, L1, L2, and L3) from the optical path and align (using the iterative procedure described earlier) the "raw" laser beam to the beamsplitter just ahead of the optical port on the gun target chamber. Position and align this beamsplitter and the "throwaway" first-surface mirror inside the chamber so that the beam falls normal to the target at the desired position and can be reflected back along the incoming optical path. If the target is specular or generates a specular component that is coincident with the centroid of the diffuse reflectance, use this specular reflection to align along the optical axis of the interferometer. Utilize the turning mirrors ahead of the interferometer to perform this alignment. If the extended path containing relay optics is used, align along this path using the additional turning mirrors installed.

If the reflected light from the target is totally diffuse, align the centroid of the reflectance along the path to the interferometer as best as can be determined and install L1. Translate this lens vertically and horizontally perpendicular to the optical path so that the diffuse spot transmitted by this lens is centered on the first alignment iris and proceed with the alignment along the interferometer rail using the turning mirrors. In any case (specular, partially specular, or diffuse reflectance), the axis of the optical path should end up well-centered on the streak camera slit. Typically, it is helpful to block the light proceeding through the delay leg at this point, especially if significant adjustments are to be made to the delay bar length along with corresponding adjustments to the translation/rotation of M2.

After the optical path is established all the way through the interferometer, the relay lenses (if used) and lenses L2 and L3 can be placed sequentially into the system. Using the irises and the center of the streak camera slit as alignment guides, translate the lenses in the plane perpendicular to the optical path so that the optical axis is well-centered in each lens. Note that the tilt of each lens in the system is important as well.

## 4.2. Tilt Adjustment of Lenses

This alignment procedure is best done with a well-defined specular spot from a mirror target. Adjust the tilt of the lenses sequentially; e.g., L1 then L2 then L3. For each lens, use a white card with a small hole upstream of the lens and align the hole to the incoming light. Examine back reflections from the lens on the back surface of the card (the card may need to be positioned at different distances to the lens in order to resolve the different back reflected spots). Ensure that the back reflections are not coming from any optic downstream of the lens by blocking the light as needed. With a typical achromat lens, one should observe two or three spots arising from different lens surfaces. Occasionally, a "bull's eye" interference pattern can be detected as well. Use the tilt and pan adjustments on the lens mount to center the spot pattern (and/or the "bull's eye") on the incoming beam (see Figure 2). If the lens is not exactly centered on the optical axis translationally, the spots

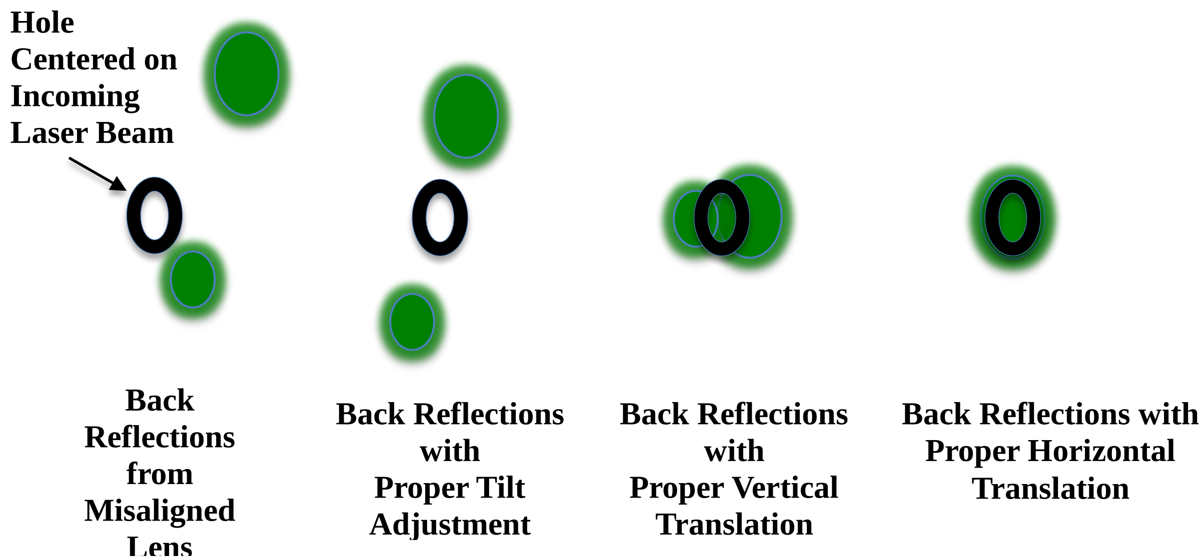


Figure 2. Typical Pattern of Back Reflections from a Spherical Lens

will appear separated either horizontally or vertically. Translate the lens so that the spots converge on the hole in the card. The spot transmitted by each lens should then be centered on the downstream irises as well. It is usually not necessary to perform a rigorous tilt adjustment of the lenses prior to every experiment. However, this adjustment should be checked periodically, especially if significant changes are made to the optical configuration (e.g., replacement of lenses).

Once all collection lenses have been placed into the system, the lenses can be translated along the optical rails in order to focus the target image onto the recombination plane. L1 is usually fixed along the axis unless there are major changes in the position of the target. L2 and L3 should provide the necessary adjustments to generate the desired image. Often, once the optical path and lens focal lengths are established, only small adjustments to the position of L3 are needed to bring the image into good focus.

In most cases, it is useful to complete the alignment of the interferometer and adjust M2 to obtain best fringe contrast at this point since it is generally easier to align with the target image illuminated by a spot rather than a line. The ORVIS VPF spreadsheet should be consulted to obtain the desired delay bar length, fringe density, and the corresponding translation distance for M2. (An initial alignment with only the beamsplitter is place was performed to establish the "zero" translation position of M2 for the spreadsheet calculations. If the beamsplitter is repositioned for any reason, this initial alignment should be repeated.

### 4.3. "Re-zeroing" the M2 Translator Position

Mount and align to a relatively diffuse target in the usual manner. Activate the translator and move M2 to a forward "Home Position." With no additional delay bars in place, measure the distance from the front surface of the beamsplitter to the reference mirror (M1) and manually position M2 to the same distance from the front surface of the beamsplitter. Search for fringes by rotating M2 and also making very small vertical adjustments needed to overlap the reference and delay images at the recombination plane. Once fringes with near optimal contrast are obtained, note the fringe density. Manually move M2 a few mm forward or backward on the rail and search for fringes again. Typically, if the fringe density is greater in this situation, it will be necessary to reposition M2 a few mm on the opposite side of the position used in your initial attempt. However, if the fringe density is less, keep moving M2 in the same direction as before. Repeat these small adjustments until you obtain a condition where the best fringe contrast is obtained for a "bull's eye" fringe pattern. One should observe the fringe contrast fall off an equivalent amount when M2 is rotated to either side of the "bull's eye." Ensure that the M2 translator is positioned on the optical rail so that the "home position" falls a little forward of the point where the best contrast corresponds to the "bull's eye." This allows a digital translator reading near the "home position" to be associated with the position the "bull's eye." The translator can then be used to make small translations (0.1 mm or so) to refine this "zero" position. Use the final measured position in the spreadsheet calculation.

Install the delay bars as needed for the particular experiment. Activate the M2 translator and "home" the translator to obtain optimal accuracy for subsequent translation. Adjust the M2 translator position to the value indicated in the spreadsheet calculations for the delay bar length and fringe density desired. Activate the motorized mirror mount and rotate/tilt M2 to overlap the reference and delay leg images. It is extremely helpful to view the target image and fringes with a video camera that can produce a magnified image on a computer or stand-alone monitor. To the extent that the geometric measurements of the interferometer have been made accurately, the fringe density at best contrast should closely correspond to the value entered in the spreadsheet. (The necessary geometric measurements for the spreadsheet were performed at the time of installation; however, these values should be re-measured if there any changes in the position of the beamsplitter or reference mirror, M1.)

### 4.4. Necessary Geometric Measurements for the ORVIS Interferometer

In order to confirm or the repeat the measurements used in setting up the interferometer, mount a specular target and align the reflected specular spot down the interferometer optical rail in the usual manner. Refer to the original reports by Bloomquist and Sheffield for the definition of the required quantities: d, d', d", □, and AC. If compl these measurements, rotate the beamsplitter to set it normal to the incoming beam. Perform the necessary tip/tilt adjustments on the beamsplitter mount to reflect the incoming beam back on itself. Set the beamsplitter rotation to the approximate angle desired and measure this rotation angle, □, by performing the measurement illustrated in Figure 3. Along a line perpendicular to the optical axis of the interferometer, measure $d_1$ (the distance to the front surface of the beamsplitter) and $d_2$ (the distance from the interferometer optical axis to the reflected spot along the perpendicular line). Simple trigonometry can be used to evaluate 2□□ from this measu and AC can be measured as indicated in the Bloomquist and Sheffield reports.

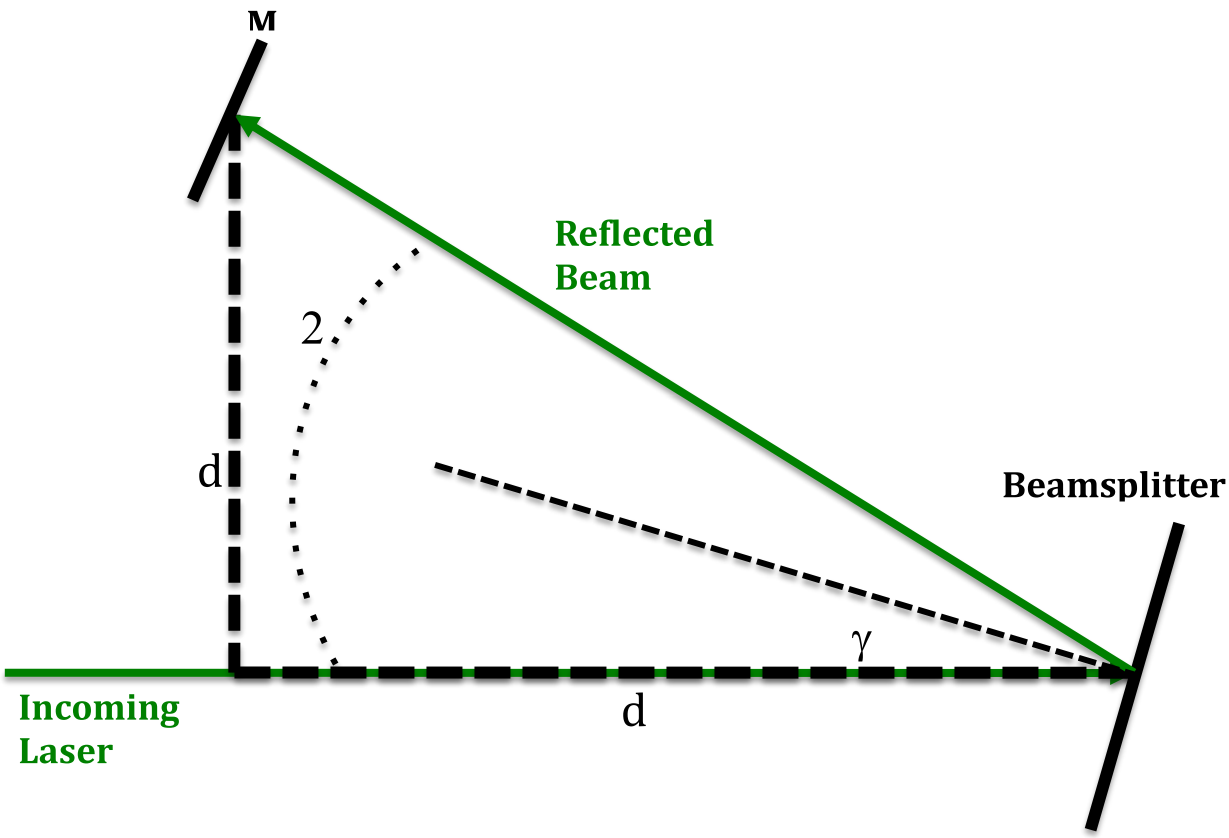


Figure 3. Right Angle Measurement of Beamsplitter Rotation Angle

Once the desired fringe density and best contrast are obtained, the line-shaping optics can be installed to generate the line illumination to be viewed by the streak camera. For this step, it is very helpful to install a video camera to view the illumination pattern on the target itself and to convey a magnified image of this illumination to the interferometer table where it can be viewed as adjustments to the optics are made. Typically four lenses (one spherical and three cylindrical) are used to generate the line illumination. The 1st lens (nearest the laser source) is a plano-convex spherical lens that focuses the laser beam to a point at a distance downstream of the lens approximately equal to its focal length. The 4th lens (furthest from the laser source) is a cylindrical lens that is used to relay this focused spot to the target in the vertical dimension. To accomplish this, the 4th lens is rotated to the proper orientation and the line-shaping lens assembly is set so that this lens is located approximately twice its focal length from both the target and the focal spot of the spherical lens. (Using simple lens formulas, it should be possible to achieve a strict 1:1 magnification; however, in practice, the true magnification often varies from this value somewhat.) The relatively long distance from the 4th lens to the target (>2 meters) dictates that the complete line-shaping optics assembly also occupies a similar distance. This is accomplished by the folded path illustrated in Figure 1. The 2nd and 3rd lenses in the assembly are cylindrical lenses oriented to focus the light in the orthogonal (horizontal) dimension. The 2nd lens is a short focal-length optic that is used to overcome the divergence of the 1st lens in this dimension. The 3rd lens (a longer focal-length optic) acts to roughly collimate the light in this dimension. These two lenses can be moved roughly in tandem to vary the length of the line segment at the target.

When installing the line-shaping optics, it is helpful to position these lenses sequentially into the system, checking the tilt and translating each lens in a manner similar to that used for the lenses L1-L3. Note that the back reflections from the cylindrical lenses are not simple spots but the principle of converging the reflections with the position of the incoming beam remains the same. It is very helpful to also view and center the light transmitted by these lenses on the downstream irises.

Once the lens translations and tilts are established, the optics can be moved forward and backward on the optical rails to achieve the optimal focus on the target. If the target image has been accurately focused onto the streak camera previously, the line illumination reaching the streak camera slit should also be narrow. Small translations of the 3$^{rd}$ and 4$^{th}$ lenses may be needed to align the line segment precisely to the slit. Check the fringe contrast again at this point. Now the fringe definition can be checked using the display of the streak camera/CCD system. Small changes to the rotation and tilt of M2 may be needed to sharpen the observed fringe contrast.

Two further points must be emphasized. First, it is vital that the overlap of the reference and delay legs to achieve best contrast be accomplished using a diffuse surface, even if the intended target surface is specular or partially specular. (It is very easy to obtain clear fringes with a specular surface even if the reference and delay legs are poorly overlapped.) Since the target imaging and interferometer optics are essentially independent, it is not necessary to access the actual target surface for this purpose; i.e., a diffusely reflecting surface (e.g., aluminum foil or a white card) can be placed on the surface or on an interferometer window in contact with the surface. Utilize this diffuse surface for alignment. The region where the fringes are visible and in decent contrast should be fairly narrow with the contrast falling off rapidly as M2 is rotated to one side or the other. Second, it is vital that the light reaching the streak camera slit be restricted to reflected light from the intended surface *only*. Especially when an interferometer window is used in the target assembly, the light from the intended surface may be “contaminated” with one or more specular reflections. (Another source of specular reflection may be the optical port on the gun target chamber tank.) A concerted effort should be made to block the unwanted reflections. Specular reflection from the target area will typically come to a tight focus at a location between L1 and L2 while the diffuse reflectance remains an extended spot. If possible, use a small object (e.g., popsicle stick, Q-tip, needle, etc.) to intercept the specular reflection(s) at this point. Only a small fraction of the desired diffuse reflectance will be thrown away by this action. Ensure that the blocking tool does not excessively vignette or shadow the image at the streak camera slit. Also, be sure to check this blocking arrangement after the line-shaping optics are installed since the pattern of specular and diffuse reflectance will change somewhat when these optics are introduced into the system.

## 5. Target Surface Preparation

The line-imaging ORVIS can be used with a wide variety of target surfaces. Specular surfaces can provide good return light for some experiments in which the interface of interest remains largely specular under impact loading. Experiments with homogeneous materials and/or ramp loading conditions can produce this result (e.g., symmetric impact loading of fused silica). In many cases, however, surfaces become relatively diffuse upon shock loading. Light reflected from such targets can become distributed over a large solid angle, possibly resulting in a dramatic overall loss of intensity as the shock arrives. While results under dynamic loading can vary greatly, it is often helpful to begin with a surface finish that produces a reflection pattern that is diffuse but is also concentrated in a cone angle that is largely accepted by the high *f/#* of the L1 lens (see Figure 4).

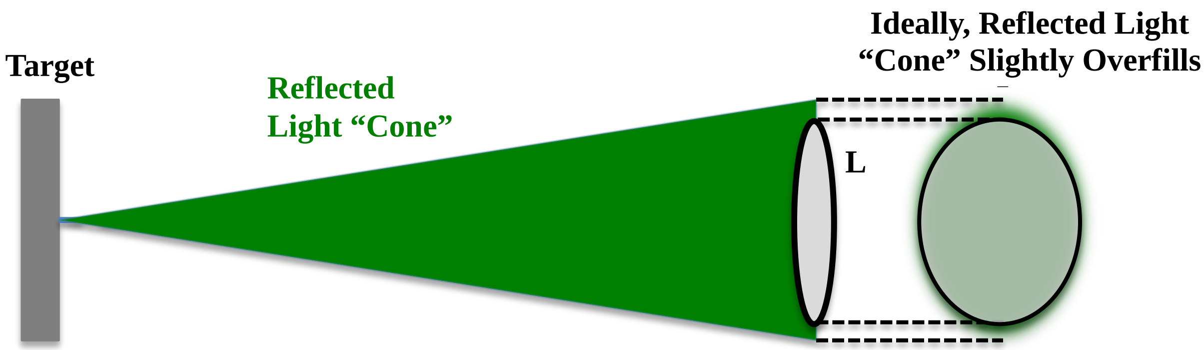


Figure 4. Illustration of Desirable Pattern of Diffuse Reflectance from Target Surface. (The actual path is folded.)

With this configuration, the loss of light intensity upon shock arrival is typically much less that that experienced with a specular surface. An even more diffuse reflector can, of course, be used; however, this may result in unacceptably low overall light intensity for recording the event. Given the wide variety of possible samples (from homogenous to very coarse heterogeneous) and surface finishes, it is impossible to give comprehensive recommendations for surface treatment. Good results have been obtained by polishing the surface to different surface finishes (or by "roughing up" a specular surface and then polishing back) or by micro-peening the surface with bead blasting techniques. Samples with relatively large particle sizes present significant challenges as well, often requiring a buffer material to smooth out the highly structured waves produced in these samples. The experimenter may expect to engage in significant "trial and error" efforts to optimize the reflecting surface for certain applications.

An additional complication arises from the fact that the line-imaging ORVIS is effectively a projection microscope (using monochromatic light illumination) that can produce highly magnified images at the streak camera. Fringes produced by the interferometer modulate the light pattern that is seen in this image. With perfectly homogeneous illumination and reflection, the fringes should correspond to a smooth sinusoidal pattern. In practice, however, surface imperfections (tiny scratches, pits, etc.) produce an underlying more or less random pattern of light and dark regions on which the fringes are superimposed. Hence, as methods are developed for generating a suitable reflected cone angle (as shown in Figure 4), attention must also be given to what effect this surface treatment has on the surface finish microstructure in order to produce as homogeneous an image as possible.

## 6. Image Acquisition

In addition to acquiring the data image (the fringe record generated in the experiment), it may be helpful to take several other images that can be useful in pre-processing the data before the supplied data analysis software is used. A background or dark field image should be acquired with the laser shutter closed and with the streak camera/CCD system operated at the same intensifier gain setting as that used for the data image. Subtract the background image from the data image in order to account for the thermal noise in the data record. If the data image is of very low intensity, it may be helpful to average several background images to obtain a less noisy record for the subtraction. It is sometimes helpful to record an image with the delay leg blocked (a "reference" image) in order to observe the underlying spatial variation in the light intensity from the target. In principle, the data image can be normalized by this record but results of this operation can be mixed. In particular, very noisy normalized records can result if the reflected light intensity is low over some regions of the image. It is often helpful to record an image of the static fringes before the data is acquired (a "baseline" image). In some cases, this image can be used to compensate for small amounts of image rotation or warping. The supplied data reduction software is configured to perform the subtraction of the baseline record from the data. This subtraction is particularly successful if the shot-to-shot performance of the streak camera is essentially constant. In principle, a flat-field image (acquired with constant illumination across the slit) would be useful in the analysis as well. This type of image can be used to account for differences in the pixel response of the detector system. However, this record is difficult to obtain in practice. Pulsed laser illumination using an integrating sphere in close proximity to the slit might be a useful approach in this regard.

Other image pre-processing steps can be useful as well. Various types of image filters (e.g., median filters) can provide positive results in "cleaning up" the image. Various approaches to enhancing the dominant frequencies in the image (e.g., FFT filtering) can be very effective, especially in the case of low-intensity or noisy records. It is, of course, very important to avoid over-processing the images as this can produce unwelcome image artifacts.

## 7. Common Problems and Likely Solutions

Low-intensity Fringe Records

- Operate the laser at higher power, if possible.
- Verify that the laser is not being attenuated somewhere in the system.
- Re-work the target surface, if possible, to obtain a better reflectivity and a more suitable cone of reflected light.
- Operate the detector system at higher gain to the extent that it doesn't compromise the dynamic range of the image.
- Verify that the A/O modulator is coming on early enough relative to the streak sweep to provide a maximum intensity.
- Verify that the first-order beam coming out of the A/O modulator has the expected power. Small changes in the modulator position, etc. can dramatically reduce the intensity transmitted.

Poor Fringe Contrast/Intensity Upon Shock Arrival

- Use a diffuse surface for fringe location and optimization to ensure that the reference and delay legs are optimally overlapped.
- Ensure that the overlap doesn't drift with time (e.g., the precision rotator is activated when it is supposed to be idle)
- Use a buffer material in the target assembly if you suspect that the emerging wave is highly structured.

Static Fringes Appearing in the Image After Shock Arrival

- Re-work the target surface, if possible, to obtain a better reflectivity and a more suitable cone of reflected light from the intended surface.
- Ensure that specular reflections from surfaces other than the intended surface are effectively blocked before entering the interferometer.

Fringes Appear Curved at Region of Best Contrast

- Re-work the beam alignment to ensure that the optical axis of the interferometer is parallel to the surface of the interferometer table. It can be helpful to set up a movable iris at the desired height and check the beam height at various positions around the table.

Fringes Do Not Have the Same Contrast or Density as M2 is Moved to Either Side of the "Bull's Eye"

- Recheck the geometric measurements used in the ORVIS VPF spreadsheet.
- Verify that the backoff distances (M2 translations) are correct. The precision translator can be in error if the proper counts/cm value is not entered into the menu.

Poor Line Image at the Streak Camera Slit

- Verify that an optimal line segment is being produced by the position of the line-shaping optics.
- Verify that the interferometer is focused on the target surface.
- Operate the laser at sufficiently low intensity or with the A/O in pulsed mode to avoid thermal blooming in intervening optics (e.g., this can definitely occur in Lexan windows under constant high-power illumination).

## 8. Appendix: List of critical components

| Application | Description | Vendor | Part# | Qty |
|---|---|---|---|---|
| 2" turning mirrors for line shaping and raising periscope | Nd:YAG Laser Line Mirror, 532nm, 2", 45° for S polarized | CVI-Melles Griot | Y2-2037-45S | 5 |
| 3" turning mirrors for image routing after collection | Nd:YAG Laser Line Mirror, 532nm, 3", 45° for unpolarized | CVI-Melles Griot | Y2-3050-45UNP | 6 |
| beamsplitter at tank portal | beamsplitter, 532nm, 50%, 4", 45° for unpolarized | CVI-Melles Griot | BS1-532-50-4050-45UNP-UV | 1 |
| interferometer beam splitter | beamsplitter, 532nm, 50%, 4", 10° for unpolarized | CVI-Melles Griot | BS1-532-50-4050-10UNP-UV | 1 |
| interferometer mirrors M1 and M2 | Nd:YAG Laser Line Mirror, 532nm, 2", 0° | CVI-Melles Griot | Y2-2037-0 | 2 |
| 1/2" etalons | laser window, no wedge, 2"x0.500", 532 AR coated at 0° | CVI-Melles Griot | W2-PW1-2050-UVOAA-532-0 | 3 |
| 2" etalons | laser window, no wedge, 2"x2", 532 AR coated at 0° | CVI-Melles Griot | W2-PW1-50.8MMX50.8MM-UVOAA-532-0 | 3 |
| line shaping optic #1 | plano-convex spherical lens, 2" dia, 200mm f.l., AR coated | Thorlabs | LA1979-A | 1 |
| line shaping optic #2 | mounted plano-convex cyl lens, 1" dia, 50mm f.l., AR coated | Thorlabs | LJ1695RM-A | 1 |
| line shaping optic #3 | mounted plano-convex cyl lens, 1" dia, 300mm f.l., AR coated | Thorlabs | LJ1558RM-A | 1 |
| line shaping optic #4 | 1000mm f.l. lens? | Thorlabs | LJ1516RM-A | 1 |
| collecting lens L1 | large 1900mm focal length lens | Edmunds Optics | 54-569 | 1 |
| collecting lens L2 | 250 mm focal length lens | Newport | PAC095 | |
| collecting lens L3 | 100 mm focal lenth lens | Thorlabs | AC254-100-A | |
| relay optics | 750mm focal length lens | Newport | PAC097 | 2 |
| piezo tip stage for M2 | New Focus (owned by Newport), 8742 controller, 8852 picomoto | Newport | | |
| linear translator for M2 | MC-5B controller, MM-4M-EX-140 GR66 stage, | National Aperture | | |
| translation rails | rails and carriers that optics are mounted on | OptoSigma | | |
| AOM | AFM-404A20 AOM unit and model ME driver | Intra Action | | |